# A Fast, Compact TPC with GEM Readout for Tracking and Electron Identification at RHIC

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Linear Collider Workshop
Berkeley, CA

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# Participants

## BNL

- **Physics**

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- **Instrumentation**

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## Yale

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## Nevis

**C-Y.Chi, W.Sippach**

## Tokyo

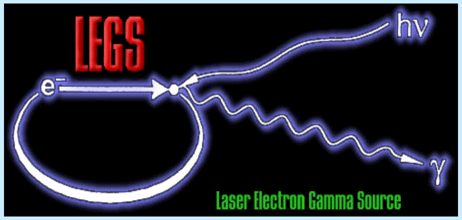
**K.Ozawa, T.Isobe, M.Inuzuka, H.Hamagaki, T. Sakaguchi, F.Kajihara,T.Gunji,N.Kurihara, S.Sawada (KEK), S.Yokaichi (RIKEN)**

## Weizmann

**I.Tserruya, I.Ravinovich, L. Shekhtman, A.Kozlov, Z.Fraenkel**

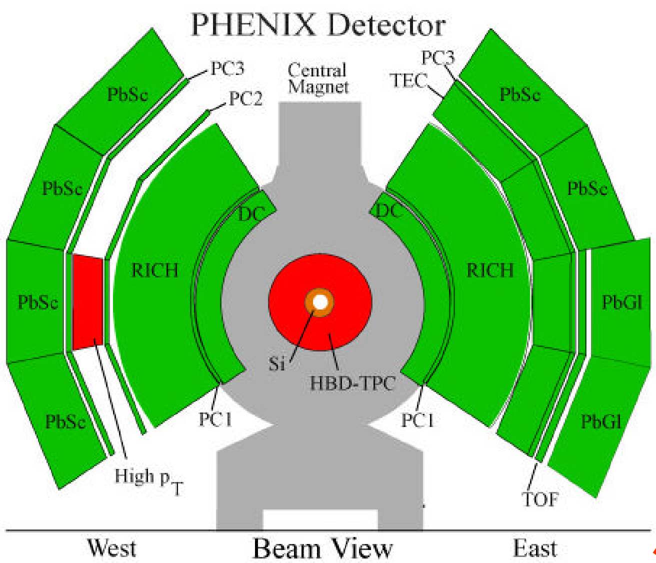
## Stony Brook

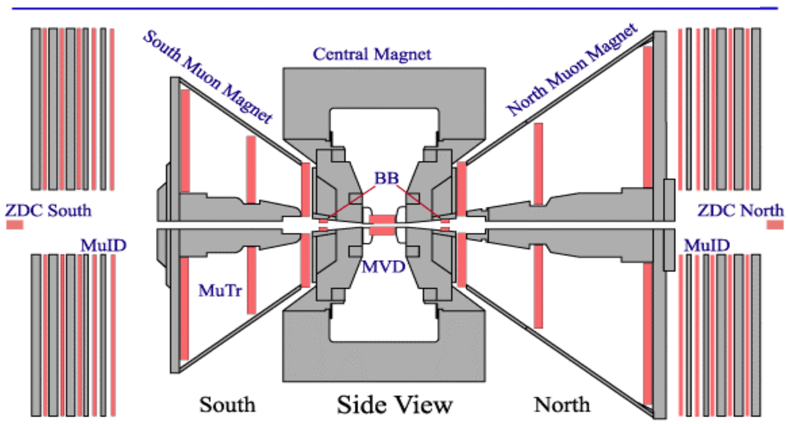
**A.Milov**

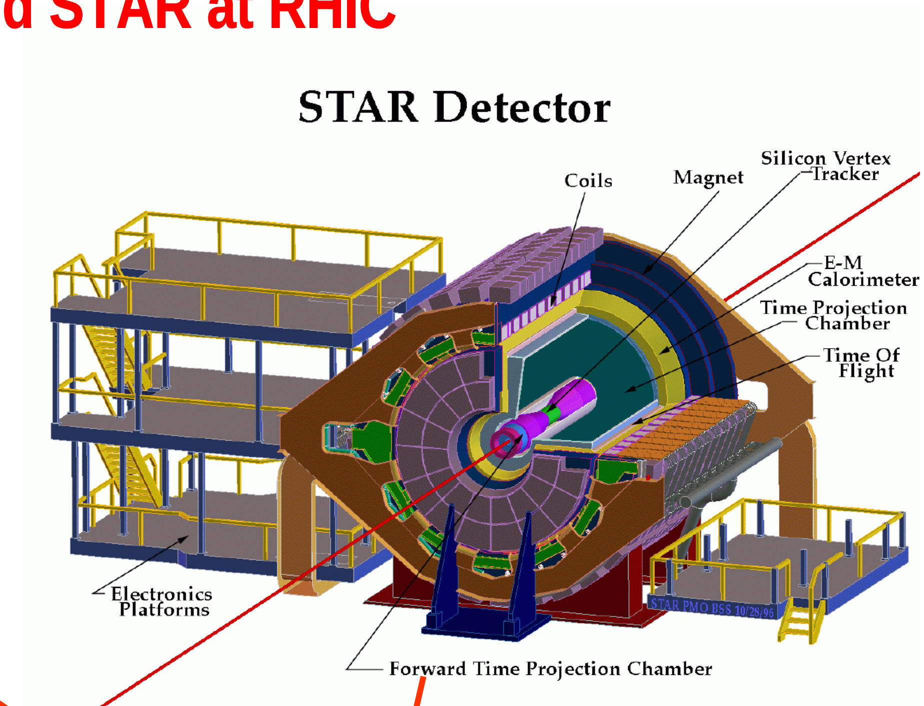


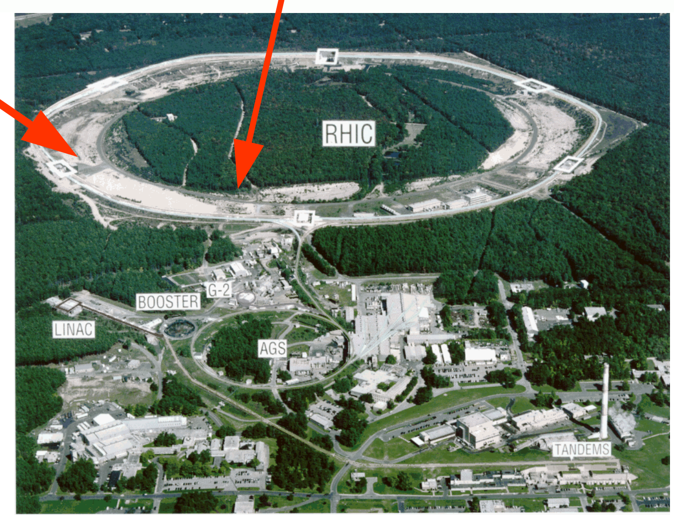

**Joint R&D with LEGS**

# PHENIX and STAR at RHIC



# PHENIX and STAR Upgrade Plans

## Extended Physics goals

- Particle Identification at high Pt
- Charm/Beauty measurements
- Low Mass Dilepton Pairs
- High Pt and Jets

## PHENIX Detector upgrades

- **Aerogel Cerenkov detector**
- **Silicon Vertex Tracker**
- **HBD and inner TPC**
- **Enhanced muon trigger**

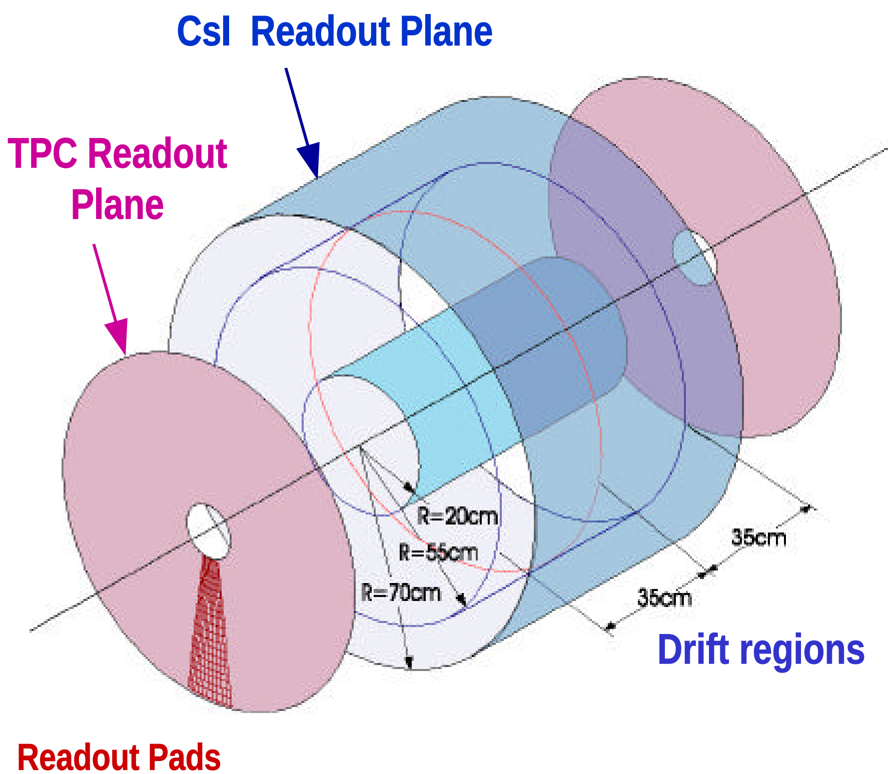
## STAR Detector Upgrades

- **DAQ upgrade ($\rightarrow$ 100 Hz $\rightarrow$ KHz )**
- **Upgrade readout electronics**
- **RPC TOF detector**
- **Silicon Active Pixel Vertex detector**
- **New fast, compact TPC**

# Physics measurements addressed by the Fast, Compact TPC in PHENIX

- Low mass lepton pairs and vector mesons
- Charm and B physics with resolved secondary verticies
  - low mass tracking just outside vertex detector
  - allows measurement in both heavy ion and pp running
- Improved inner tracking for PHENIX
  - increased **h** and **f** coverage
    (needed for jet and **g**-jet physics)
  - tracking through the magnetic field
    (improves momentum resolution, the ability to measure real low $p_T$ tracks, and to reject high $p_T$ background tracks)

# TPC/HBD Detector

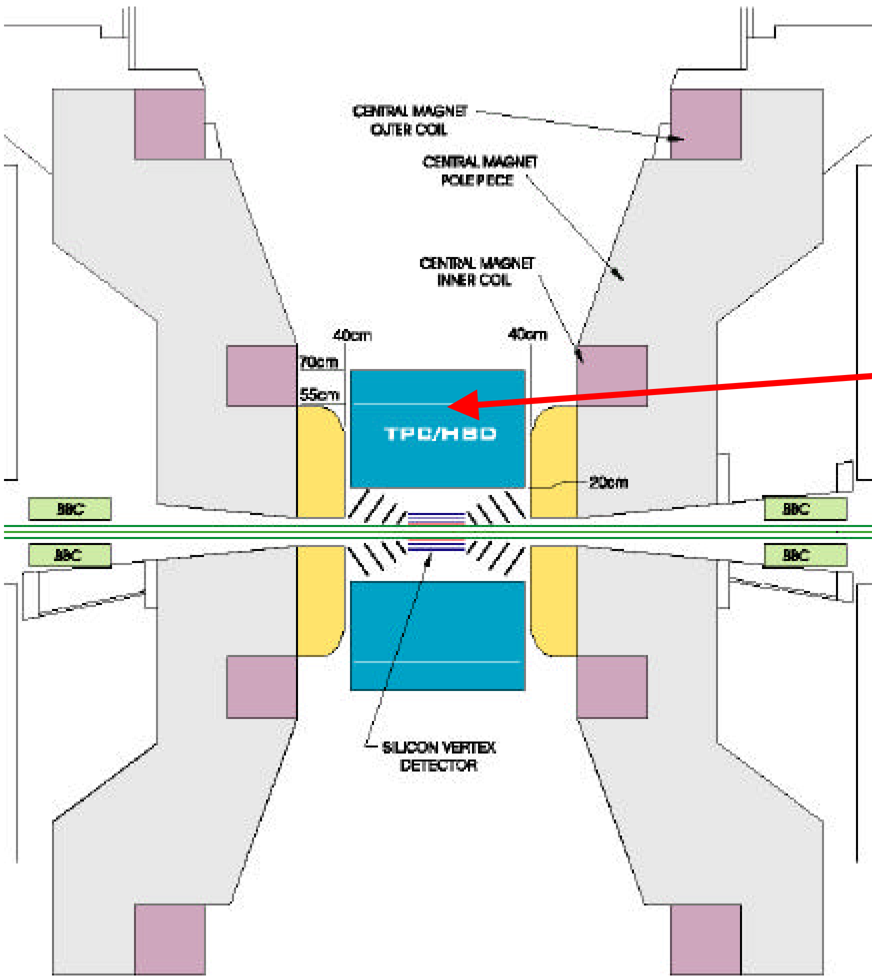



**GEMs are used for both TPC and HBD**

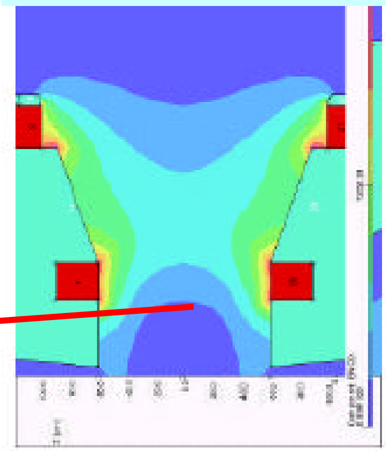
- **Fast, compact TPC**
  **R<70 cm, L< 80 cm, $T_{drift} \leqslant$ 4 msec**
- **Serves as an inner tracking detector in both HI and pp, providing tracking through the central magnetic field**
  **D f = 2p, |h| $\leqslant$ 1.0**
  **Dp/p ~ .02p**
- **Provides electron id by dE/dx**
  **$\Rightarrow$ e/p separation below 200 MeV**
- **HBD is a proximity focused Cherenkov detector with a ~ 50 cm radiator length**
- **Provides electron id with minimal signals for charged particles**

  **$\Rightarrow$ "Hadron Blind Detector"**

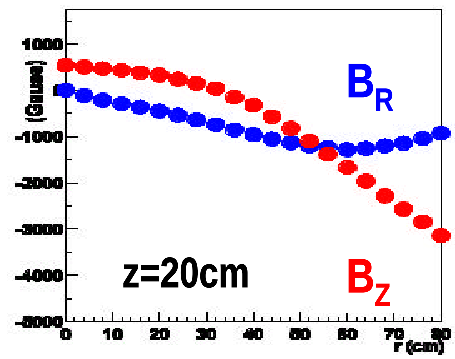
# PHENIX Inner Magnetic Field



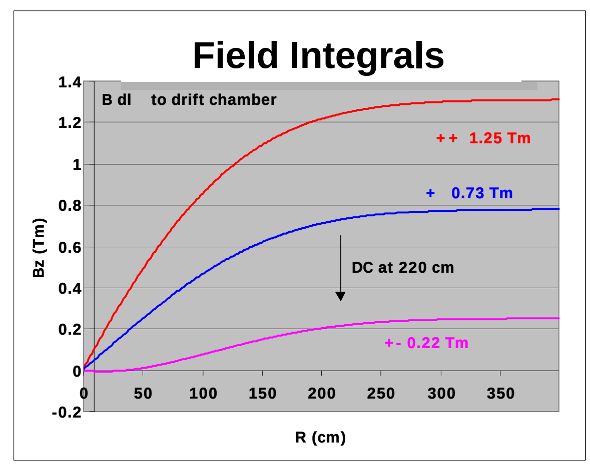

**± Configuration**



**Inner field itself is non-uniform**



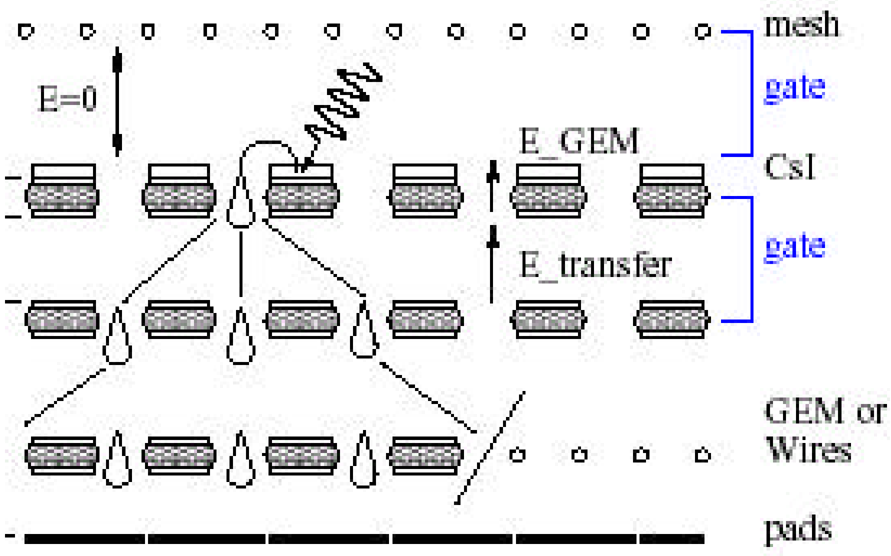

**Inner Coil creates a "field free" ( Bdl=0) region inside the Central Magnet**



# Hadron Blind Detector

## Multistage GEM detector with CsI Photocathode

- CsI photocathode deposited on outer GEM foil (must first deposit Ni+Au on GEM foil)
- Multistage GEM used to detect few tens of photoelectons
- Minimal ionization for charged particles in region above first GEM foil
- Fairly coarse segmentation of readout plane (~ 10 cm$^2$ pads)



# Choice of Gases

## HBD

- Need deep UV transparency for highest photoelectron yield
- Windowless design $\Rightarrow$ same gas for radiator as working gas for GEMs

| Gas | Ecutoff (eV) | $N_0$ ($cm^{-1}$) | dE/dx (keV/cm) |
|---|---|---|---|
| $CF_4$ | 11.5 | 936 | 7 |
| $CH_4$ | 8.5 | 185 | 1.5 |
| Ne | 15 | 2664 | 1.6 |
| Ar | 9 | 255 | 2.4 |

## TPC

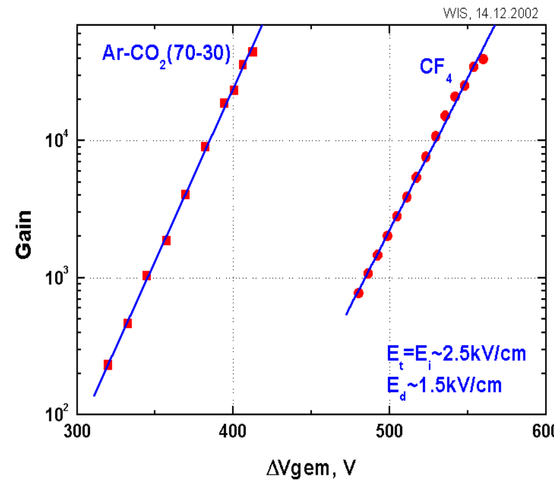
- Fast drift velocity (~ 10 cm/msec)
- Low diffusion
- High dE/dx
- Same drift gas as working gas for GEMs

**$CF_4$ (or mixtures containing $CF_4$) look most promising**

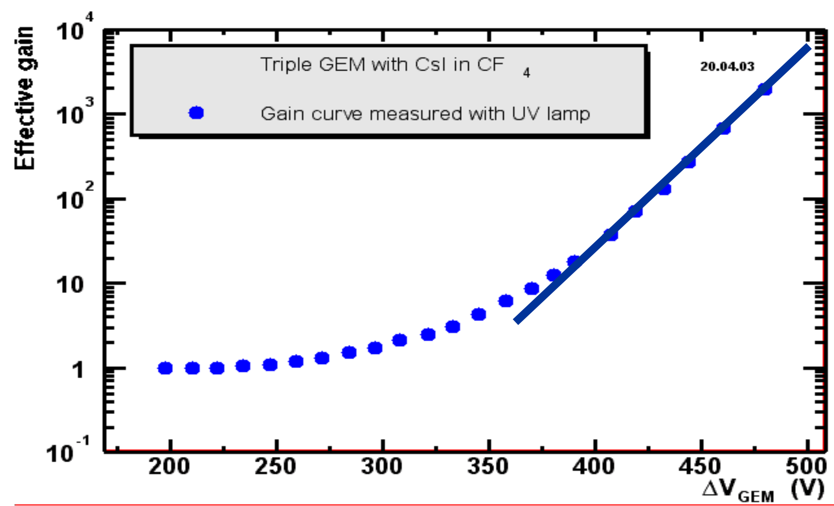
**Would like to find a single gas (or gas mixture) which would work as a drift gas, radiator gas and working gas for GEMs**

# HBD R&D at Weizmann

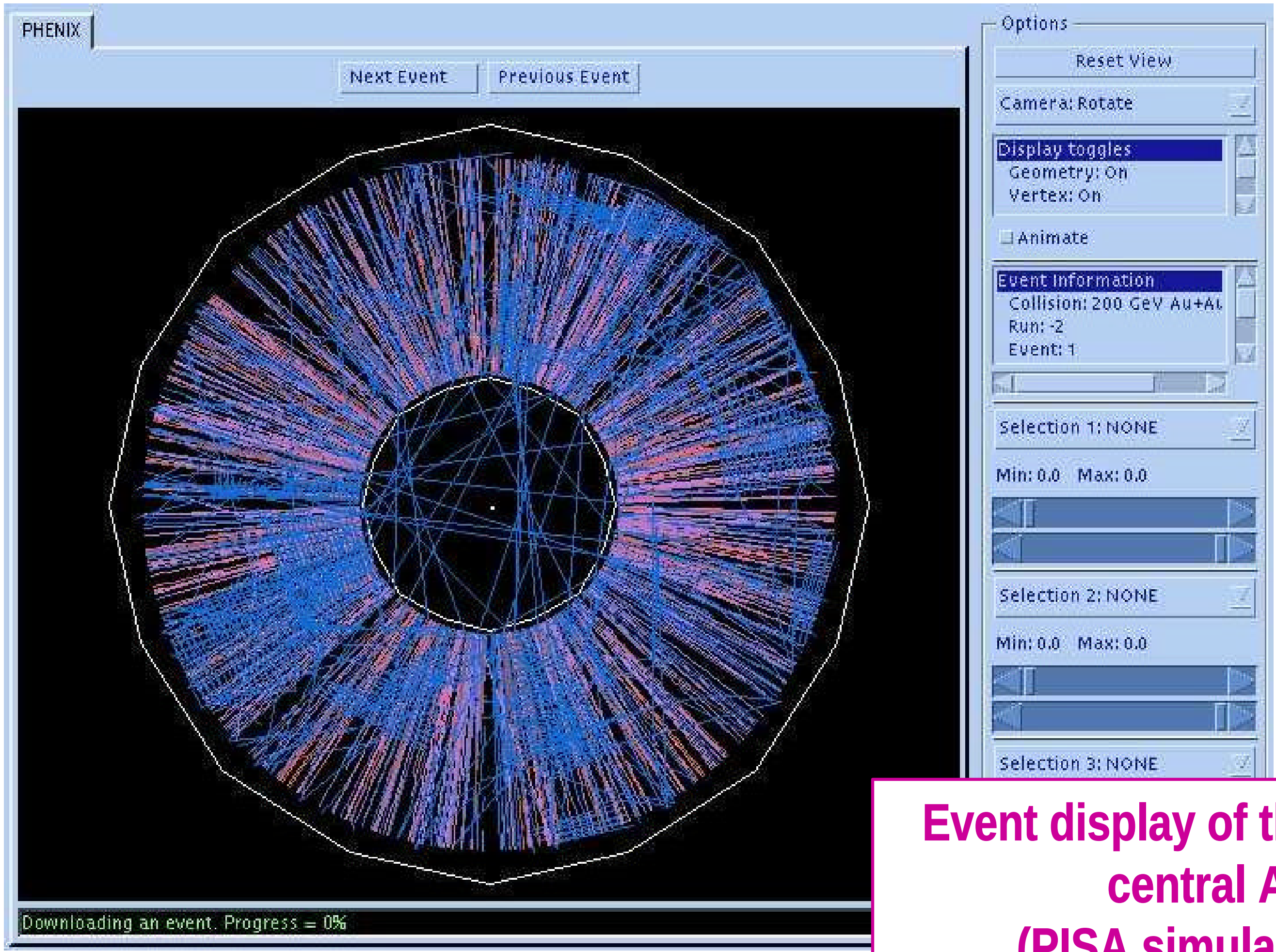
See talk by I.Ravinovich
(N25-3, Gas Detectors II, Wed, 10/22, 10:30-12:00)




Triple GEM operating in $CF_4$
with CsI photocathode



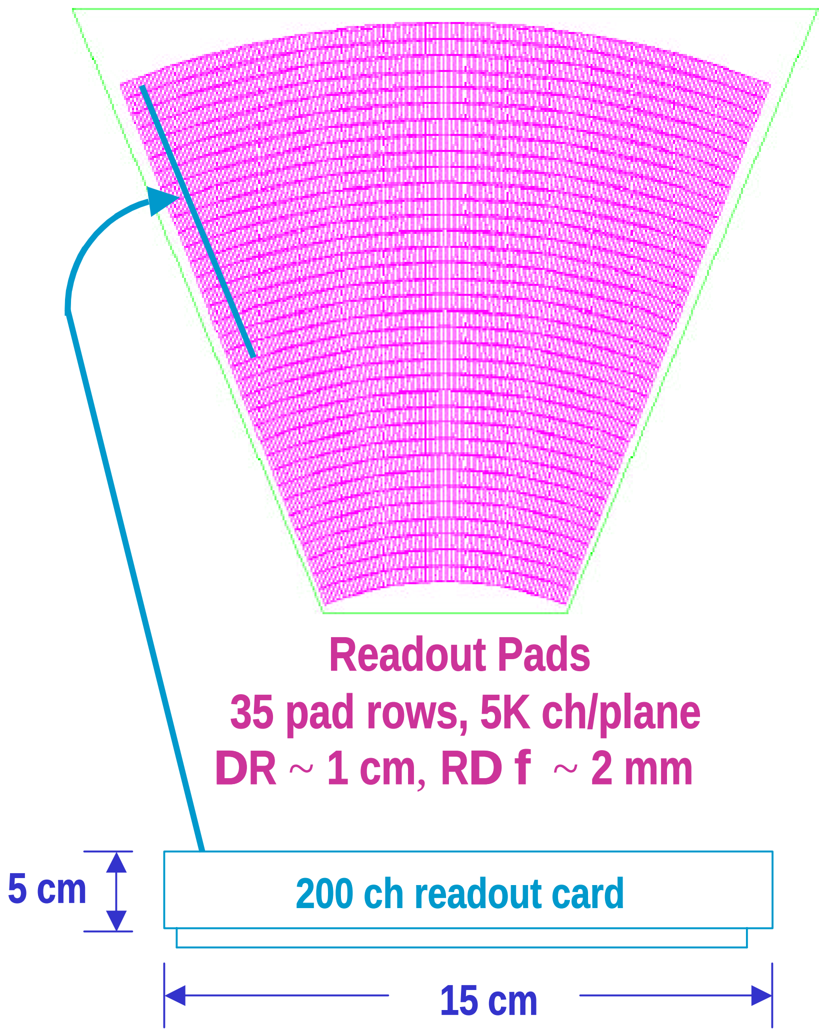
# PHENIX TPC Tracking Simulation




**Currently developing TPC tracking and pattern recognition software using existing PHENIX tracking detectors and future VTX detector**

**Event display of the PHENIX TPC for a central Au-Au event (PISA simulation - J.Mitchell)**

# TPC Readout



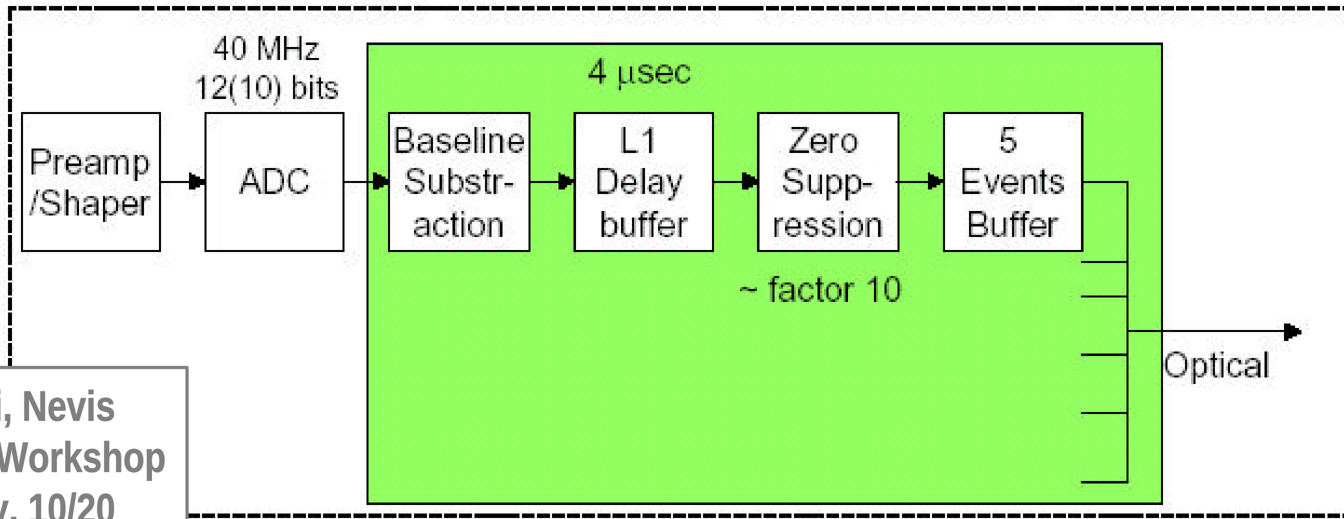

## Readout parameters

| | |
|---|---|
| Number of pads | 80K |
| Pad size | 2x10 $mm^2$ |
| Drift time | 3.5 **m**sec |
| Sampling rate | 40 MHz (25 ns) |
| Sampling resolution | 2.5 mm, 8 bits |
| Number of samples | 140 |
| Unsuppressed data volume | 11 MB |
| Suppressed data volume (~1/10) | 1 MB |
| Actual data volume | 100 KB |
| Buffer latency | 4 **m**sec |
| Readout time | 40 **m**sec |
| Data transmission rate | 200 Gbit/sec |
| Power per channel | 100 mW |
| Total power | 8 KW |

## Requirements

- Very high density readout
- Need to minimize power
- Low noise, zero suppression
- Minimize data volume (triggering)

# TPC/HBD readout electronics




C-Y.Chi, Nevis
TPC-MPD Workshop
Monday, 10/20

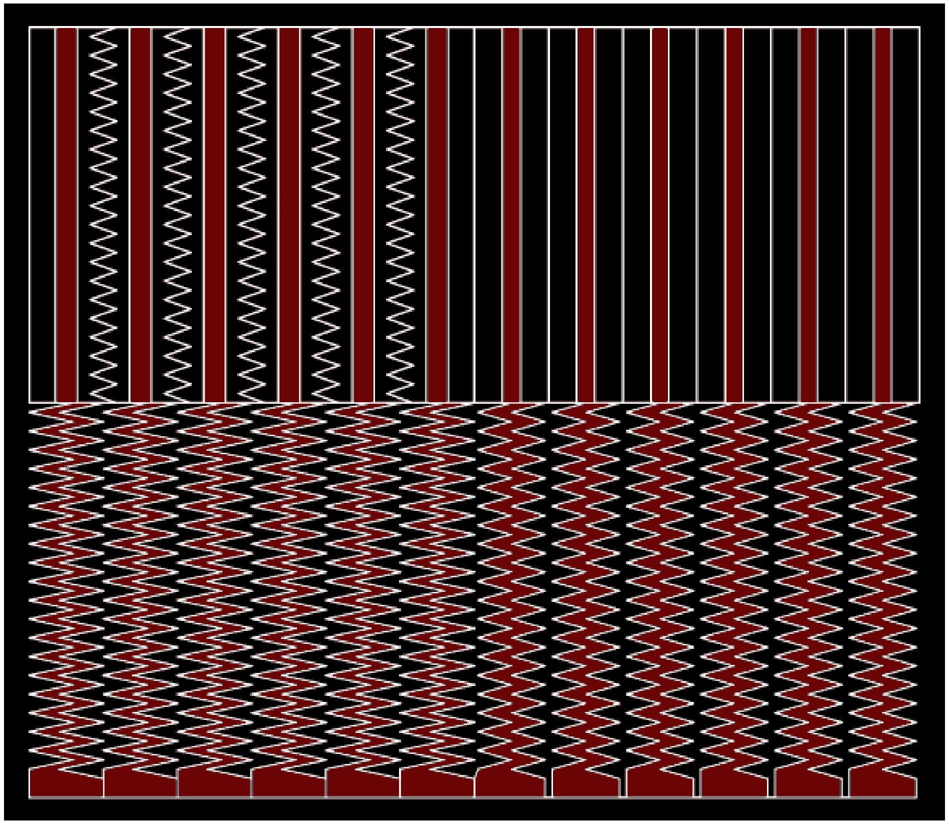
- High density, low power preamp and shaper (custom ASIC)
- 40-50 MHz, 8-10 bit FADC (TI, AD - Nevis)
- Digital baseline subtraction, zero suppression
- Provide buffering for Level 1 trigger (~ 5 events)

**Similar 32 ch preamp/shaper being developed for medical imaging**
**0.18 mm CMOS, ~ 4 mW per channel**
**Final ASIC 4.3 x 1.6 mm$^2$**

**See talk by J-F. Pratte (N1-7, Analog & Digital Circuits I, Monday, 10/20, 13:30-15:15)**

# Interpolating Pad Readout

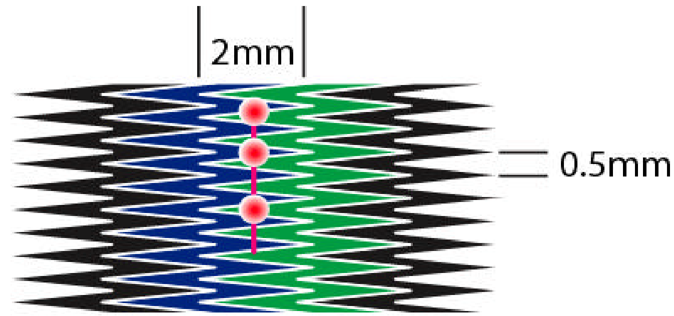
**Two Intermediate Strips**

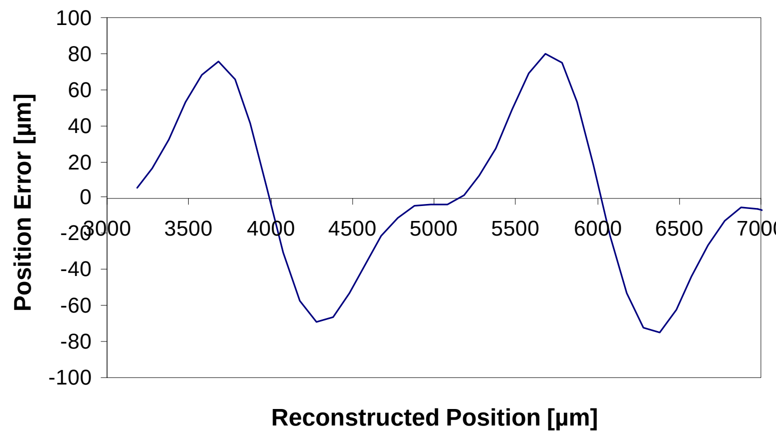


**Single Intermediate Zigzag**

**B. Yu et.al., IEEE Trans. Nucl. Sci. Vol. 50, No. 4. (2003) 836-841**

**Fine "Zigzag" pattern**

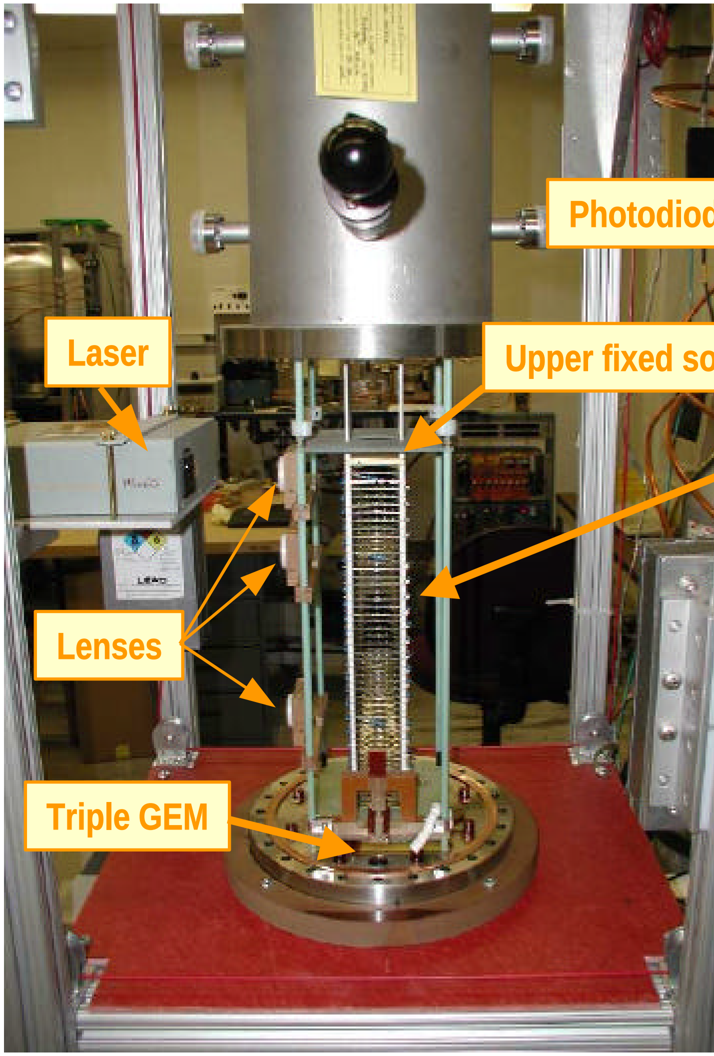


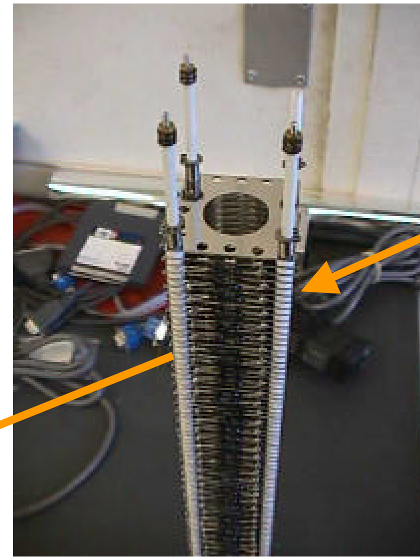

**Overall position error: 93μm rms**

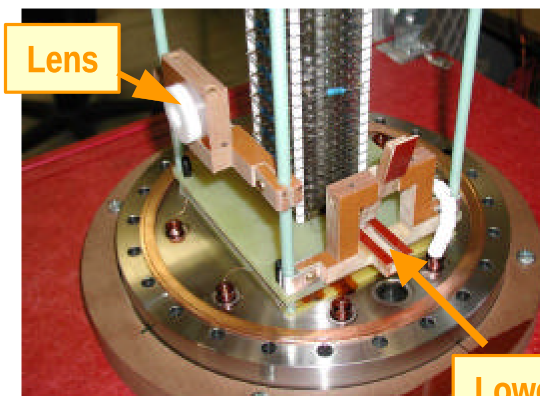
**Including ~ 100μm fwhm x-ray p.e. range, 100μm beam width, alignment errors**

# Test Drift Cell




Lab 2-86 in Physics



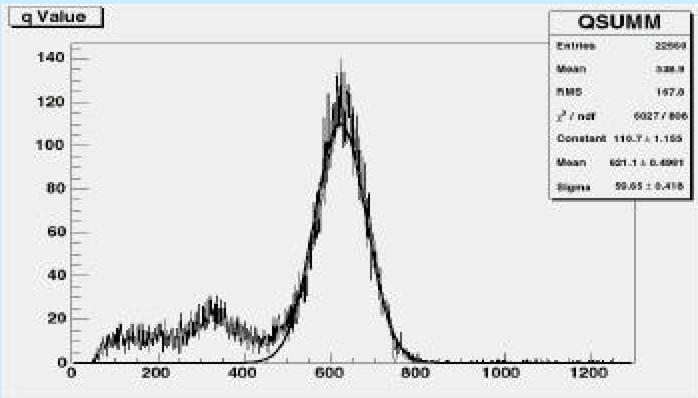




**Used to study**

- Drift velocities
- Drift lengths
- Diffusion parameters
- Energy loss (dE/dx)
- Study impurities
- Readout structures
- Field cage design

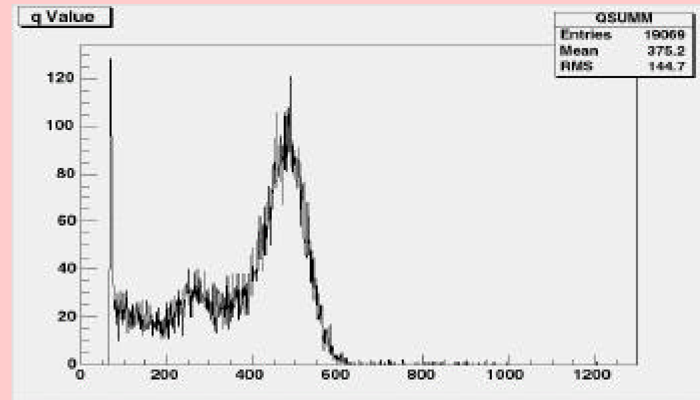
# Drift Cell Measurements

## $Ar/CO_2$ (80/20)



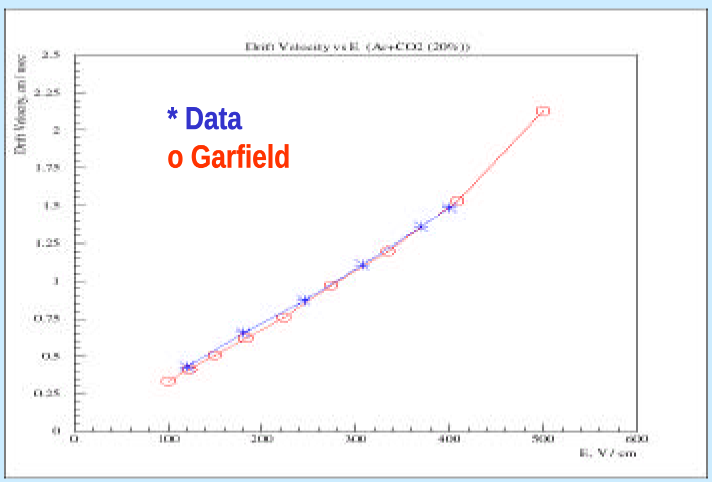

22% FWHM/mean

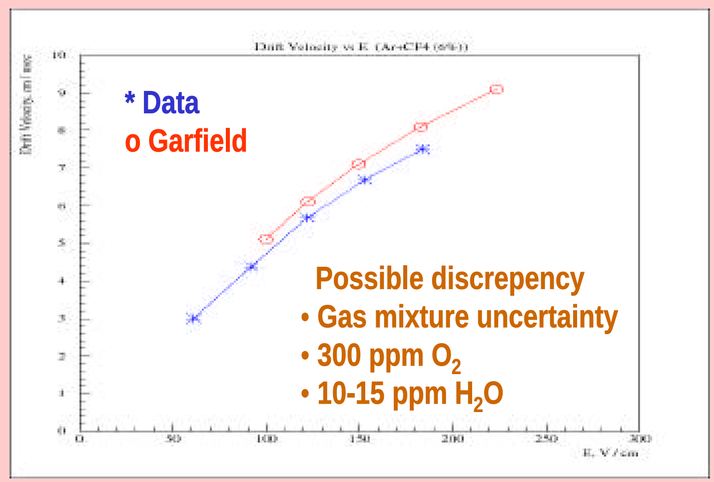
## $Ar/CF_4$ (95/5)




28% FWHM/mean

**Energy Resolution**
(Top $^{55}$Fe source)



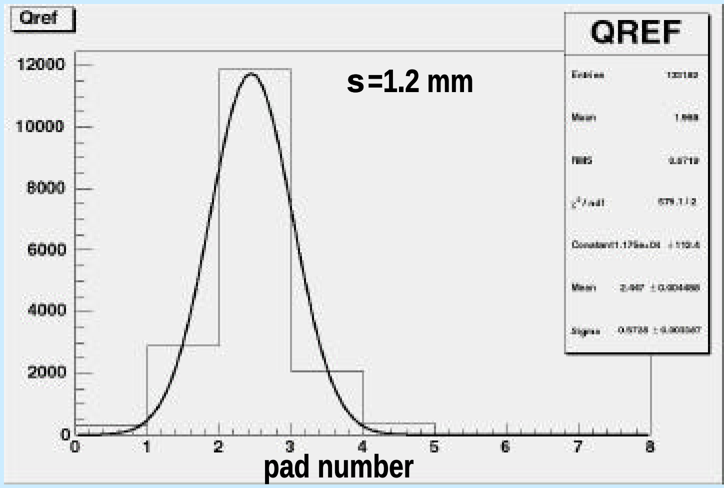



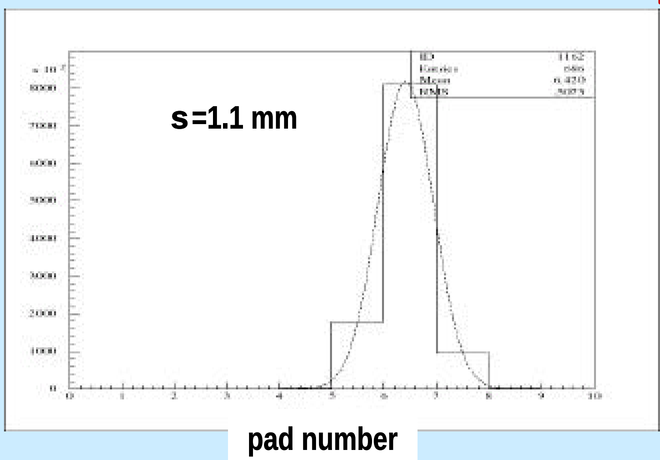

**Drift Velocities (laser)**

# Charge Distribution from Drift Cell

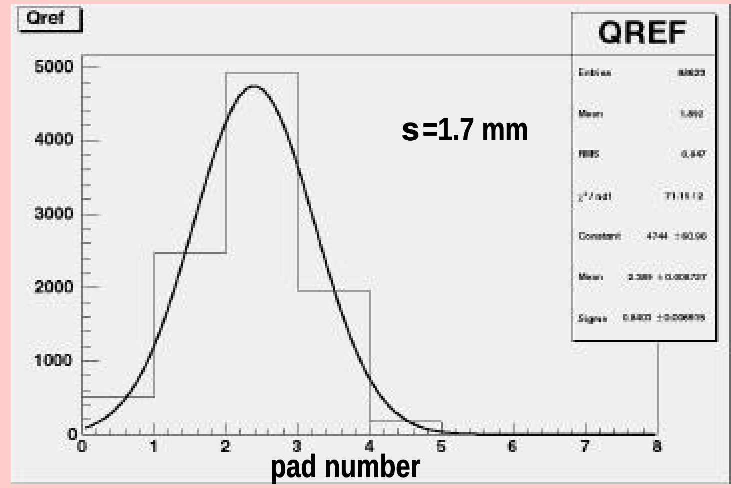
(top source, 2 mm pad readout)

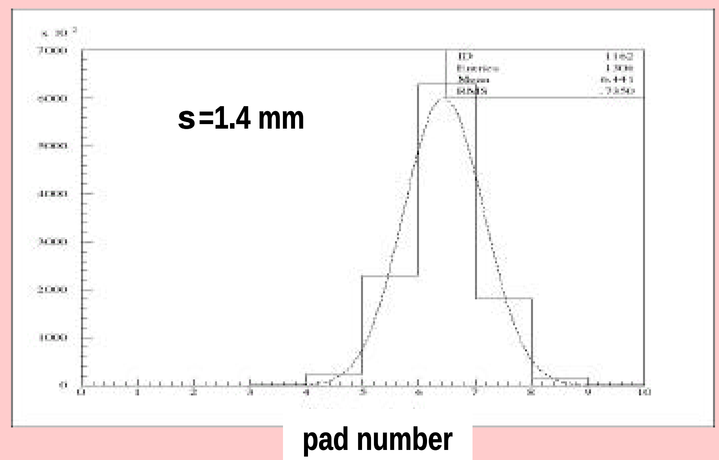
## Ar/$CO_2$ (80/20)




## Ar/$CF_4$ (95/5)



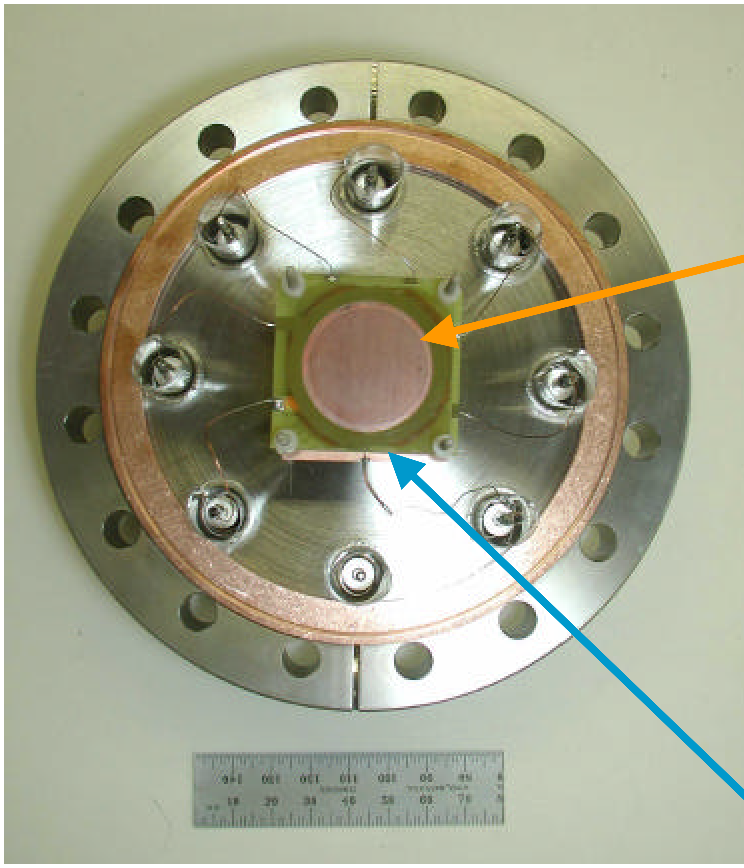



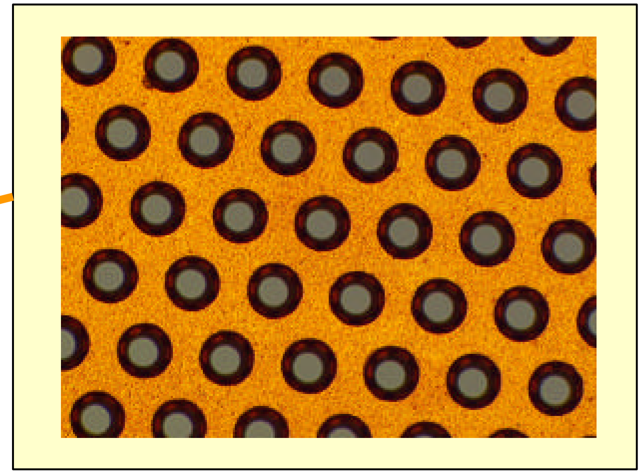

Measured

Simulation (N.Smirnov)

# Testing Small 3M Foils

**(courtesy of J. Collar, Univ. of Chicago)**





80 **m**m (55 **m**m) holes spaced in a hexagonal pattern with 140 **m**m pitch (approx. same as CERN foils)

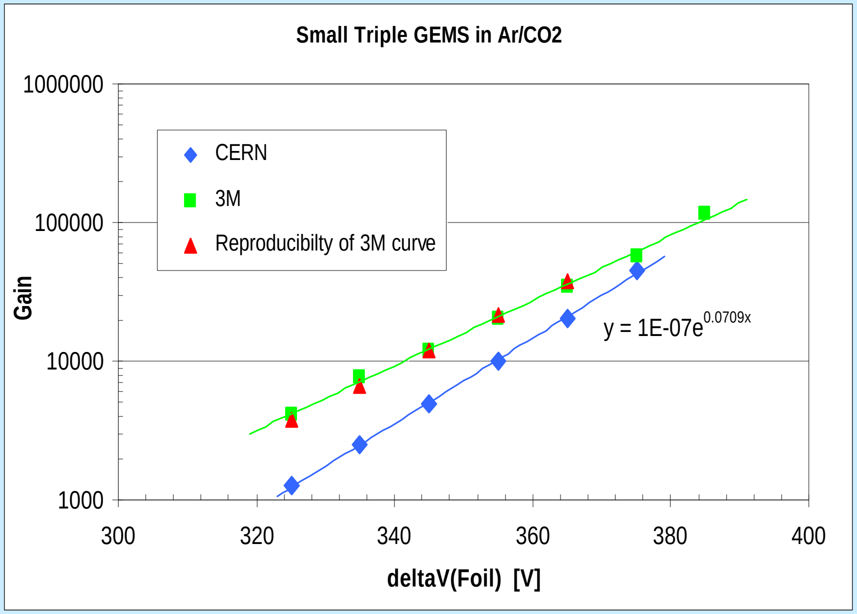
Visually looks to be excellent quality

3 stage GEM with three 1” dia. 3M foils

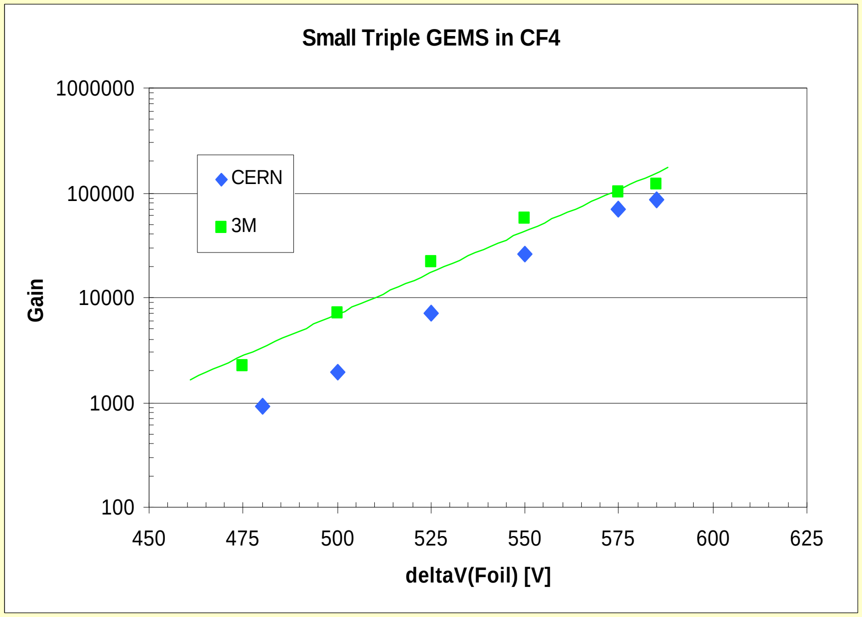
**(2 x 1.5 mm transfer gaps + 2 mm induction gap)**

# Comparison of Small Triple GEMS

## Ar/$CO_2$ (80/20)



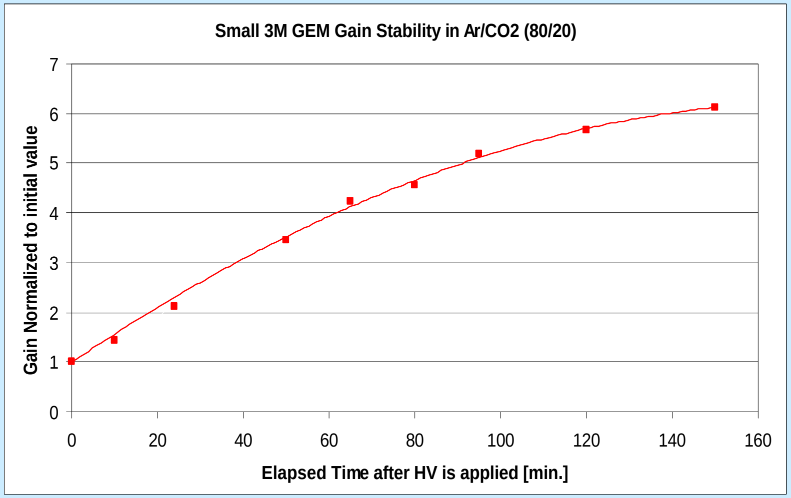

## $CF_4$

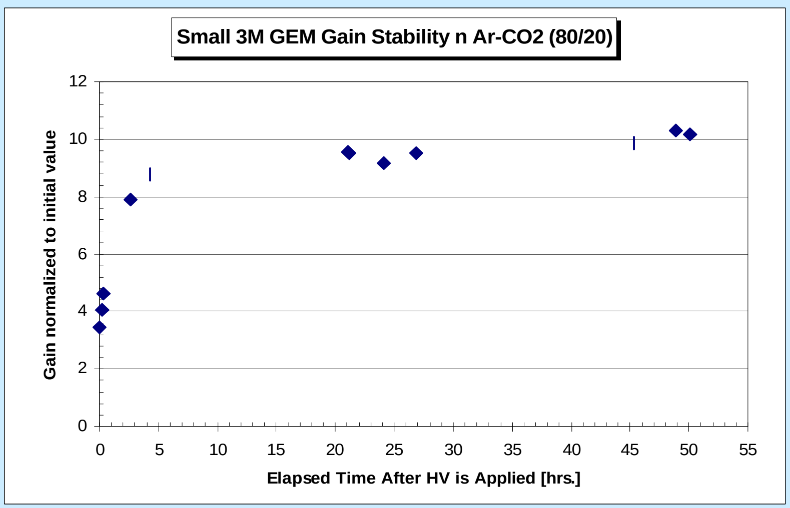



3M GEMs give higher gain and have somewhat different slopes

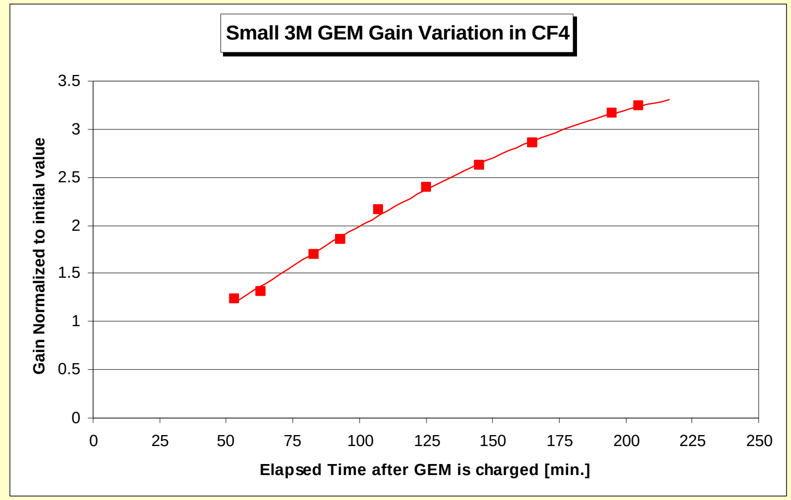
# Gain Stability - Small 3M GEMs

## Ar/$CO_2$ (80/20)




## $CF_4$

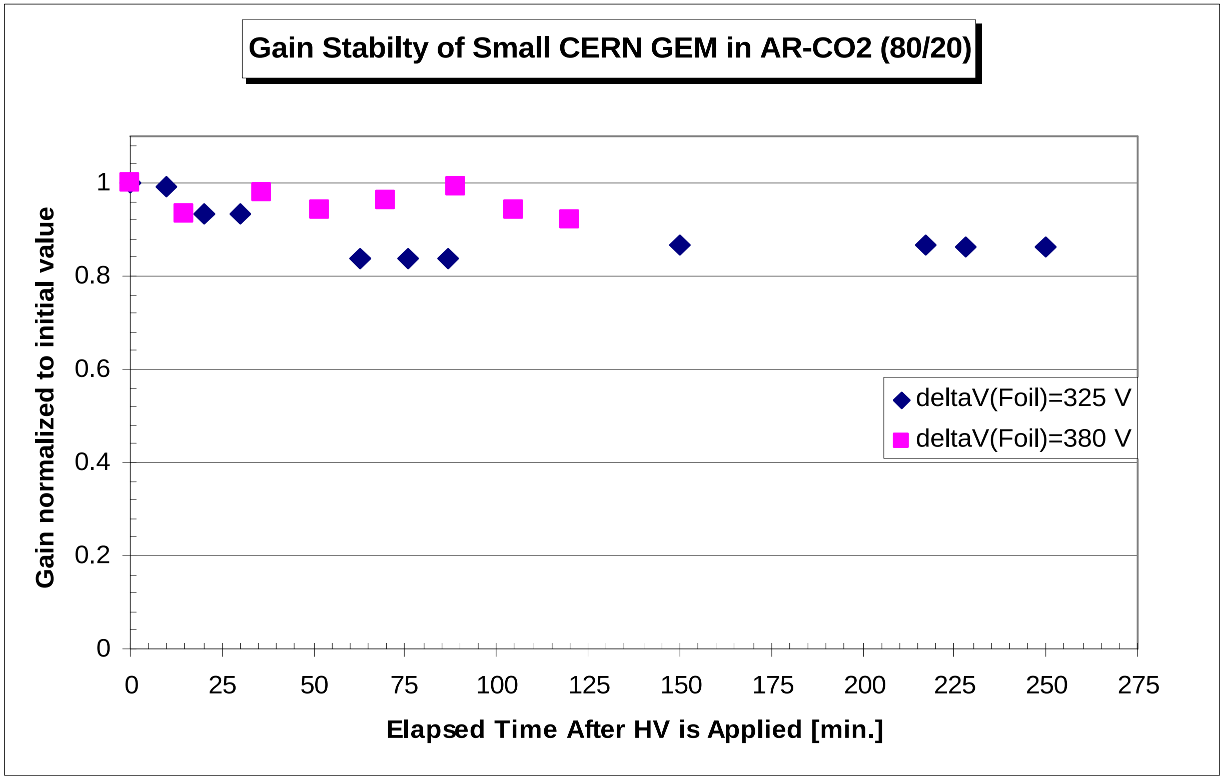



We observe a large gain variation with time with the small 3M GEMs

Time scales involved imply a possible charging effect in the foils

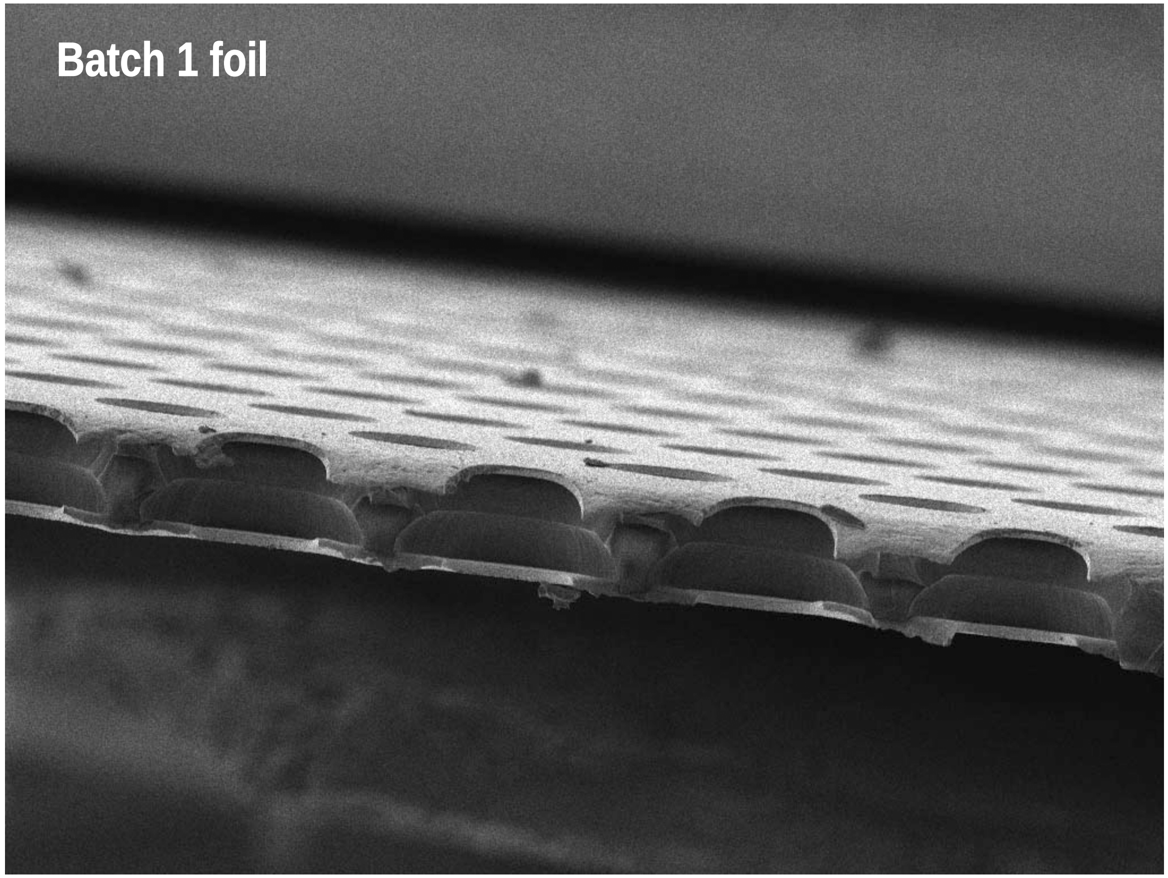
(Gas: 35 ppm $H_20$, <1ppm $O_2$)

# Gain Stability - Small CERN GEMs in $Ar/CO_2$




No large gain variations observed with small CERN GEMs

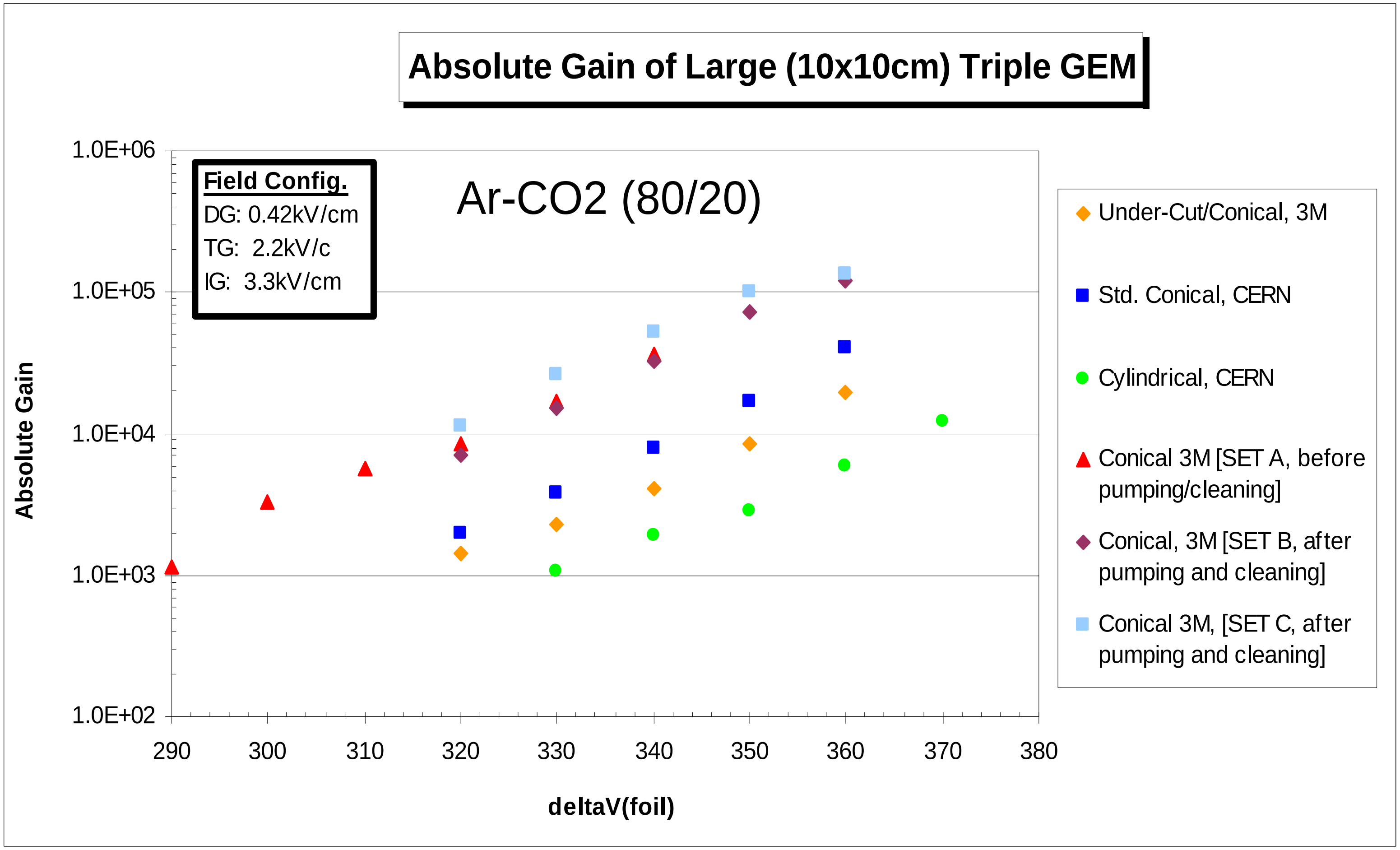
# Large (10x10 cm$^2$) 3M GEM Foils



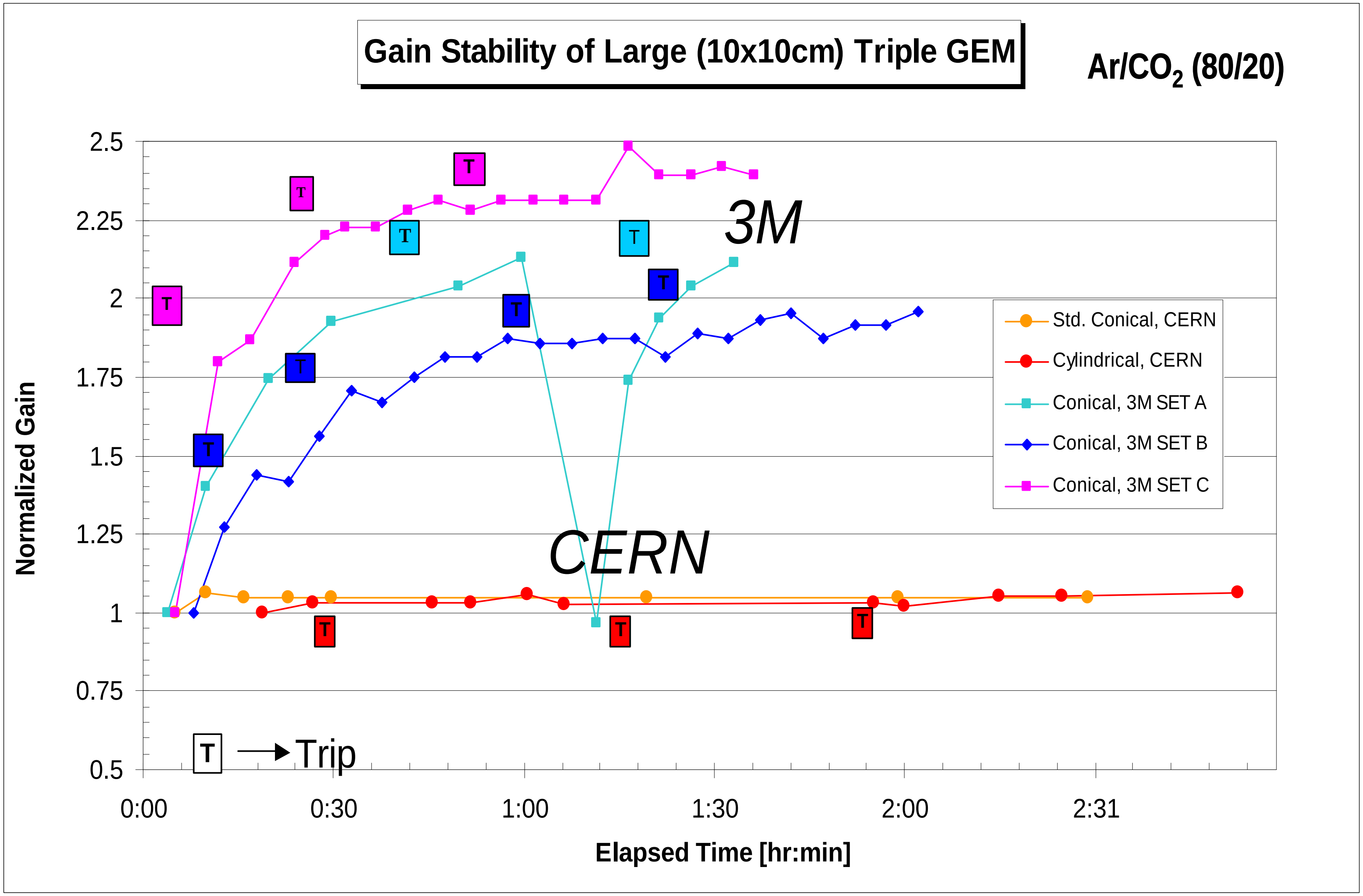

- **1st batch - "undercut" (faster etching kapton $\Rightarrow$ "over etched")**
- **2nd batch - "conical" (standard kapton but smaller holes)**

**(70mm $\rightarrow$ 40 mm vs 85 mm $\rightarrow$ 55 mm)**

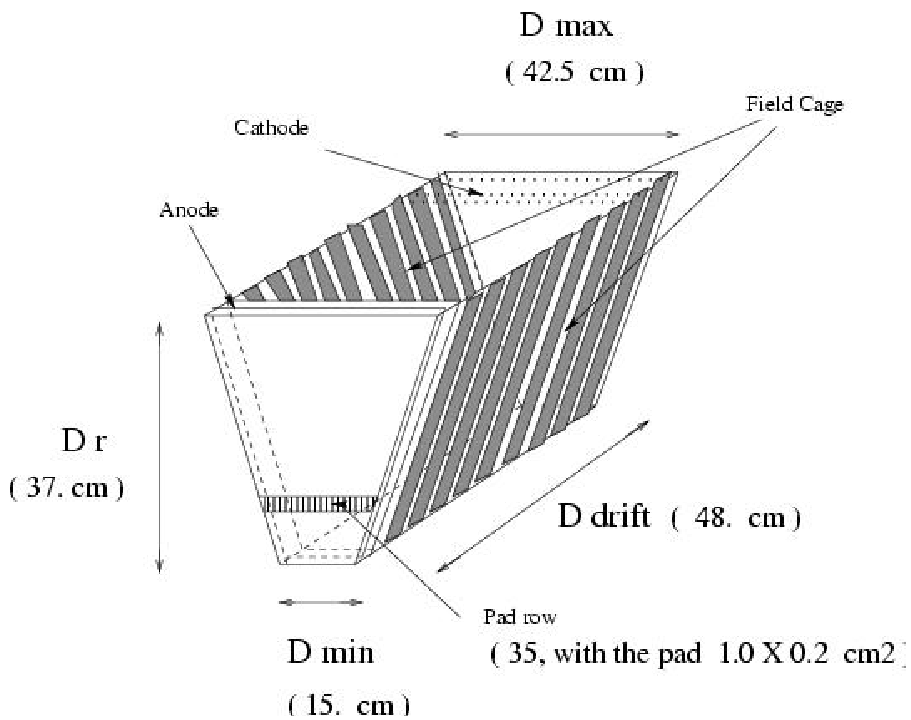
# Comparision of Gain Curves for 10x10 cm$^2$ Foils



# Gain Stability - Large Foils



# TPC Prototype - To be built this year




- Full size module
- Tests field cage design
- Tests materials to be used in actual construction
- Allows testing with cosmic rays
- Provides structure on which to design and study readout plane
- Test bench for new readout electronics

# Summary

- We have an ambitious goal to build a single detector that will serve many purposes:
  - Fast drift, high resolution TPC
  - Hadron Blind Cherenkov Detector
  - Operate in high multiplicity heavy ion and high luminosity pp collisions
- Requires meeting new challenges in detector technologies
  - GEM detectors w/CsI photocathodes
  - Operation with $CF_4$
  - New, high density, low power readout electronics
  - High data volumes and data rates
- We need a supplier of good quality GEM foils for all future development work, and are interested in working with all potential vendors